U.S. DEPARTMENT OF ENERGY | Office of Electricity Delivery and Energy Reliability

Electricity 101

EPA Webinar
June 11, 2015

Gil Bindewald
Eric Rollison

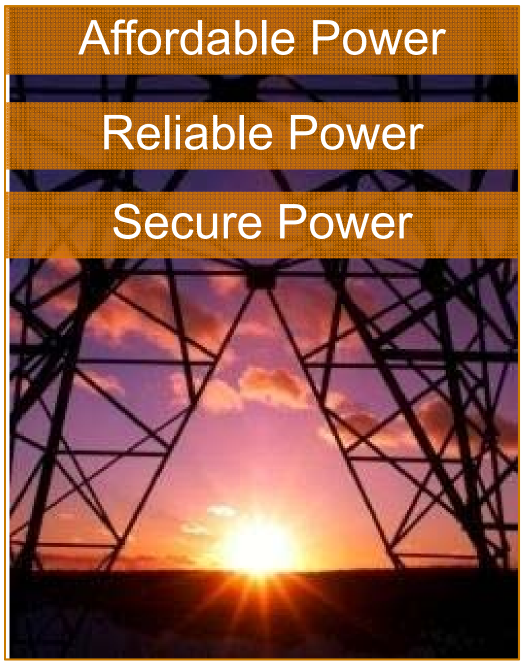
SECTION 1: OVERVIEW

Electricity's Role in Society

Electricity plays a vital role to our economy and national security. Most Americans can not describe what it is or where it comes from. Yet, we know the impact that electricity plays on nearly all aspects of our lives: *national security; health and welfare; communications; finance; transportation; food and water supply; heating, cooling, and lighting; computers and electronics; commercial enterprise; and even entertainment and leisure.*

Electric System Must Meet Evolving Expectations

Historical Expectations



Emerging Expectations

Integration of diverse set of generation resources

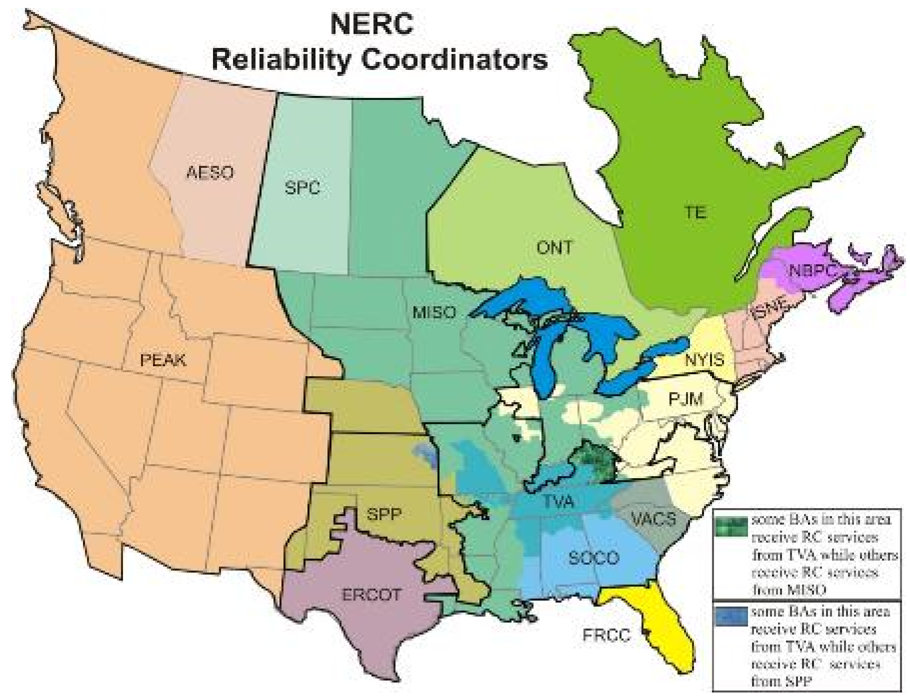
Maximize benefits of end-use efficiency and storage

Electrify transportation sector to reduce dependence on imported oil

Meet environmental constraints

Challenge Ahead is Complex

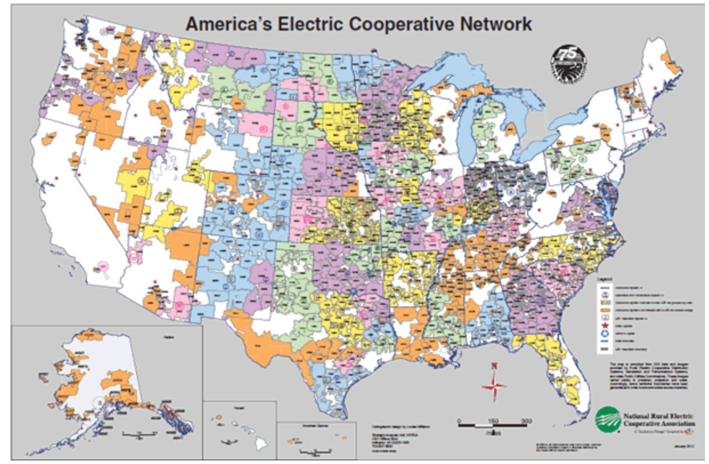
- Over 3000 utilities with diverse business models
  - Investor-Owned Utilities
  - Electric Cooperatives
  - Public Power/Municipal Utilities
  - Federal Government
- Limited demand growth
- Increased self generation (changing revenue stream)
- Diverse markets and regulatory frameworks
- Increased operational complexity
  - Changing generation & load
  - Cyber/physical concerns
  - Weather events

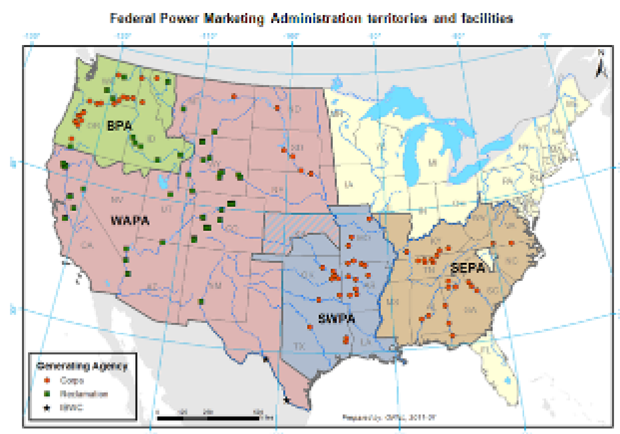


Source: North American Electric Reliability Corporation (NERC)

Electric Industry

- ***Investor-Owned Utilities -- 192***
  - Account for a significant portion of net generation (38%), transmission (80%), and distribution (50%)
- ***Publicly-Owned Utilities and Cooperatives -- ~2,900***
  - Account for 15% of net generation, 12% of transmission, and nearly 50% of the nation's electric distribution lines
- ***Independent Power Producers -- ~2,800***
  - Account for 40% of net generation
- ***Federal Government***
  - Owns 9 power agencies (including 4 Power Marketing Administrations and TVA) with 7% of net generation and 8% of transmission
- ***Electric Power Marketers – 211***
  - Accounts for approximately 19% of sales to consumers

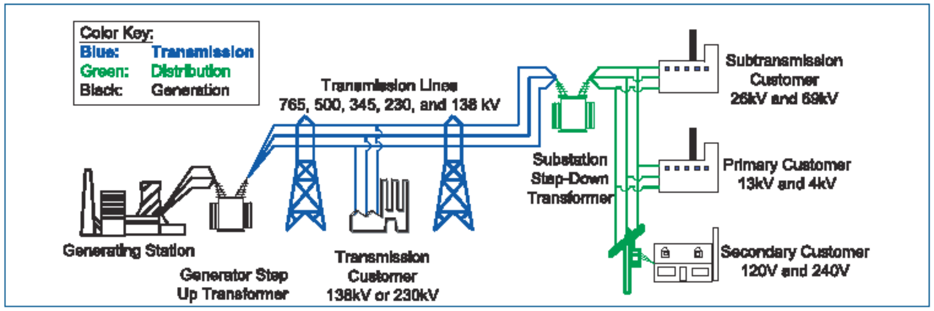


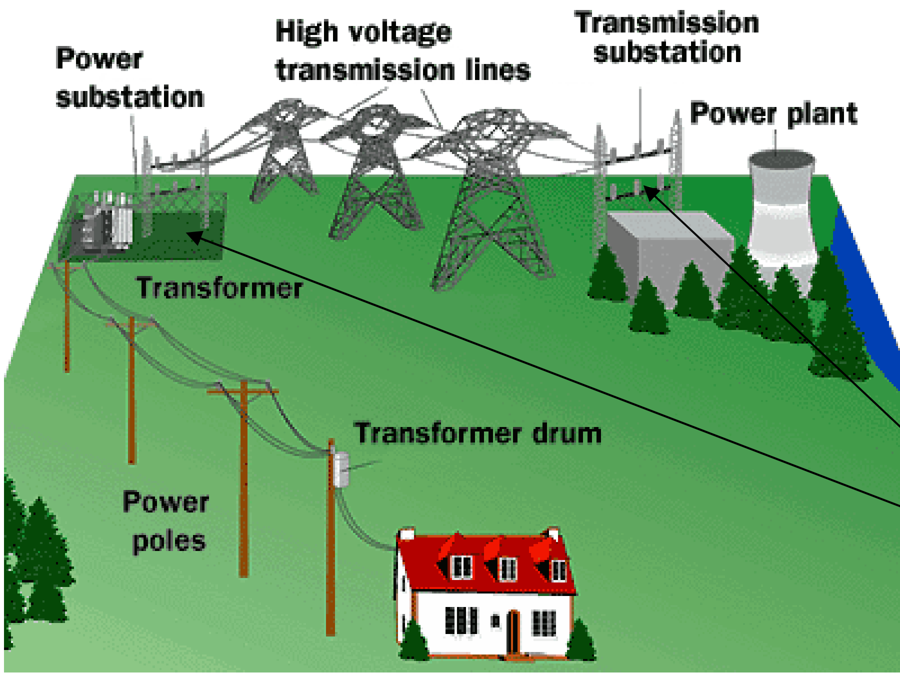


Sources: *EIA, Electric Power Annual 2013, March 2015*
EIA, Annual Energy Review 2011, Chapter 8 (Electricity)
2014-15 Annual Directory & Statistical Report, American Public Power Association
NRECA Co-op Facts & Figures, www.nreca.coop

U.S. DEPARTMENT OF ENERGY | Office of Electricity Delivery and Energy Reliability

Electric Power Systems





Source: How Stuff Works

Electric power systems involve the management of interconnected components needed to generate and deliver electric power to customers economically, reliably, and safely.

Four major components:

Load: *Consumes electric power*

Generation: *Produces electric power*

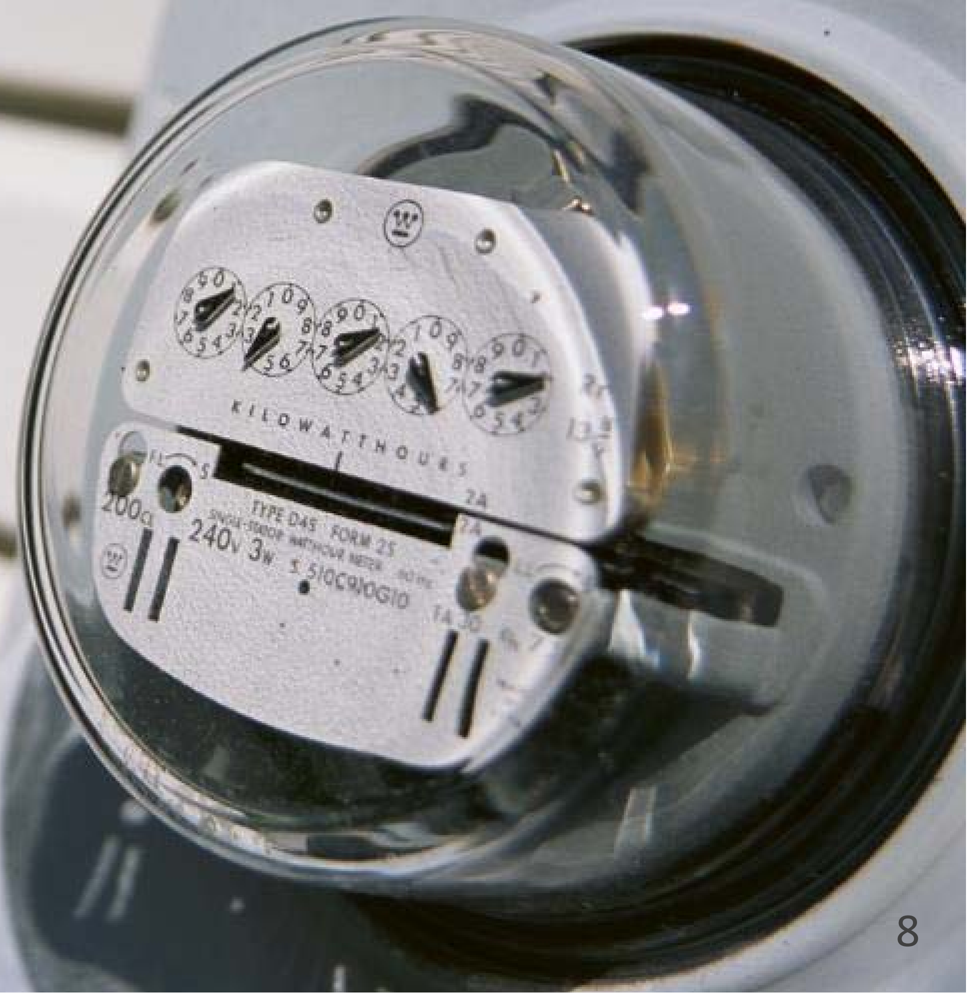
Transmission (and Distribution): *Transmits electric power from generation to load*

Control Centers: *Coordinate generation and transmission assets for economy and reliability*

Components are joined together at “buses” or substations.

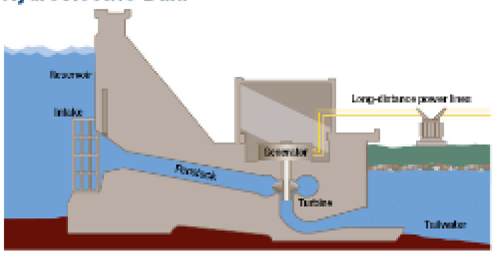
Load

- **Load (from a utility perspective) typically begins at the meter.**
- **The meter measures a customer's energy use.**



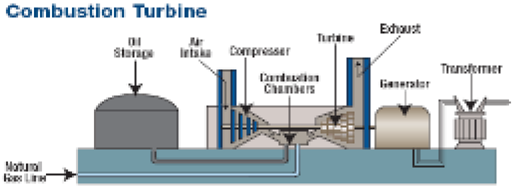
Generation

Hydroelectric Dam



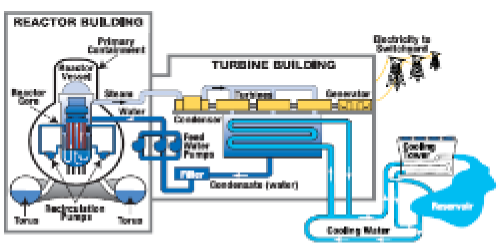
Water from the reservoir rushes through the penstock into the powerhouse. The water spins the turbine, which drives the generator. Inside the generator is a large electromagnet that spins within a coil of wire, producing electricity.

Combustion Turbine



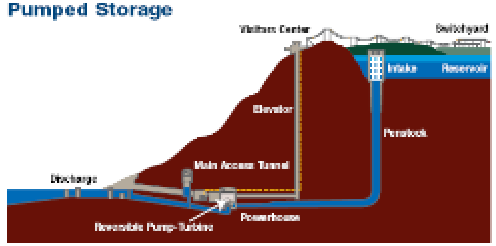
The turbine burns either natural gas or oil. Fuel is mixed with compressed air in the combustion chamber and burned. High-pressure combustion gases spin the turbine, which drives the generator.

Nuclear—Boiling Water Reactor



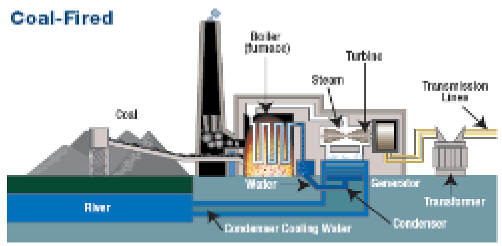
Water is heated through the controlled splitting of uranium atoms in the reactor core and turns to steam. Pumps force the water through the reactor at top speed, maximizing steam production. Steam drives the turbines that turn the generator to make electricity. Cooling water drawn from the river condenses the steam back into water. The water is discharged directly back to the river, reused in the plant, or cooled first in the cooling tower before discharge or reuse.

Pumped Storage



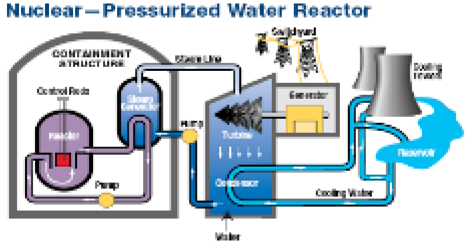
During periods of low power demand, the pump-turbine pumps water up into the mountaintop reservoir. During periods of high demand, water from the mountaintop reservoir flows into the penstock, or large pipe, to the turbines and generator, spinning them to produce electricity in the underground power plant.

Coal-Fired



Coal burned in the boiler heats water to produce steam. The steam spins the turbine, which drives the generator. Several TVA coal plants include equipment called scrubbers to reduce sulfur dioxide emissions, and all have some form of controls to reduce nitrogen oxides (not depicted in this diagram).

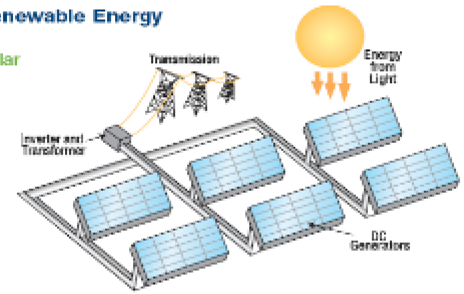
Nuclear—Pressurized Water Reactor



Water is heated by splitting uranium atoms in the reactor core, then held under high pressure to keep it from boiling. It produces steam by transferring heat to a secondary water source, and the steam is used to generate electricity. As in a boiling water reactor, river water condenses the steam and is then discharged back to the river, reused, or cooled in the tower.

Renewable Energy

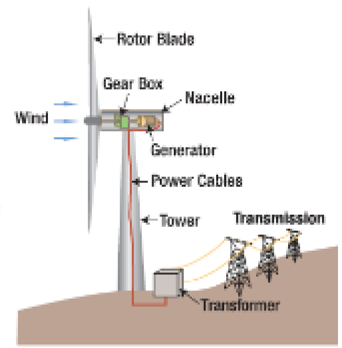
Solar



Photovoltaic (PV) systems use semiconductor cells that convert sunlight directly into electricity. Direct current from the PV cells, which are arrayed in flat panels, flows to inverters that change it to alternating current.

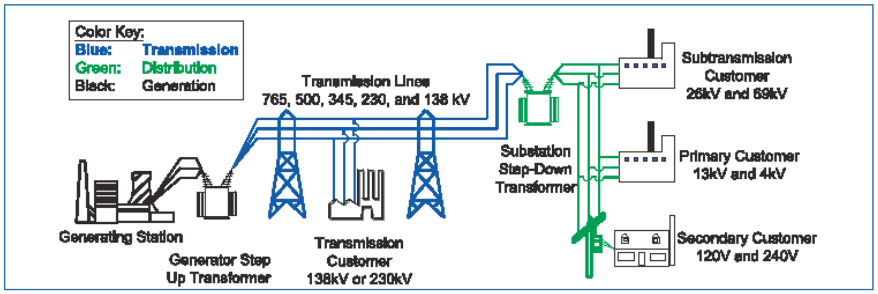
Wind

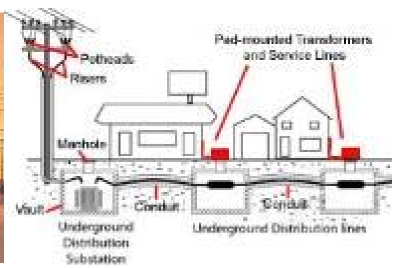
The turbine's long rotor blades catch the wind's energy. In the housing at the top of the tower, the rotor-driven gearbox increases the speed of the drive shaft that turns the generator to make electricity. A transformer boosts the voltage and feeds it to the power system.



Source: *TVA (2007)*

Substation





Source: OSHA

- Changes voltage from one level to another
- Connects electric generating plants to the system
- Makes interconnections between the electric systems of more than one utility
- Switches transmission and distribution circuits into and out of the grid system
- Regulates voltage to compensate for system voltage changes
- Measures electric power qualities flowing in the circuit, and connect communication signals

Major Differences between Transmission and Distribution Systems

Size and scale

Operation is fundamentally different

- Transmission system: operated actively
- Distribution system: operated passively

Failures lead to different consequences

- Transmission system: widespread blackout or large block load shed
- Distributed system: impacted power quality, local area

Transmission/Subtransmission Voltage Levels
69kV up to 765kV AC; 800kV HVDC

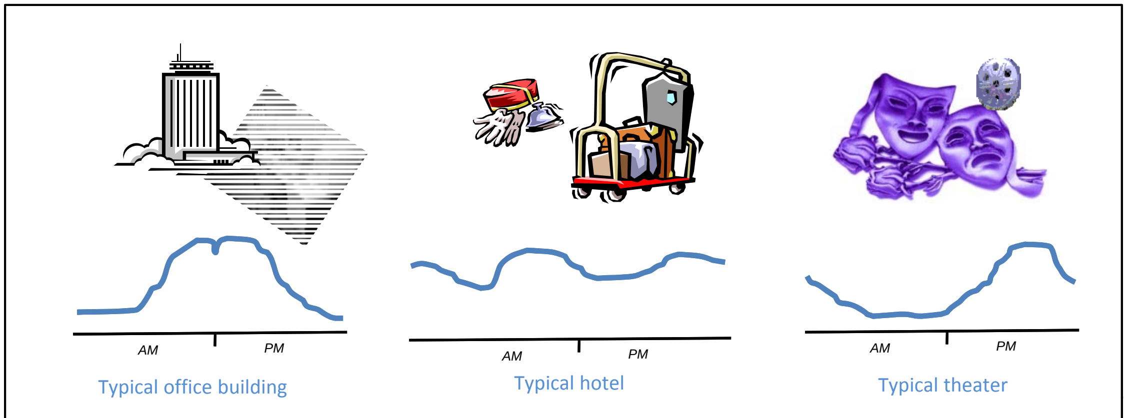
Distribution Voltage Levels
Medium Voltage
4.16 kV – 46kV
Low Voltage
480 V
120/240 V (single-phase)

SECTION 2:
SYSTEM OPERATIONS

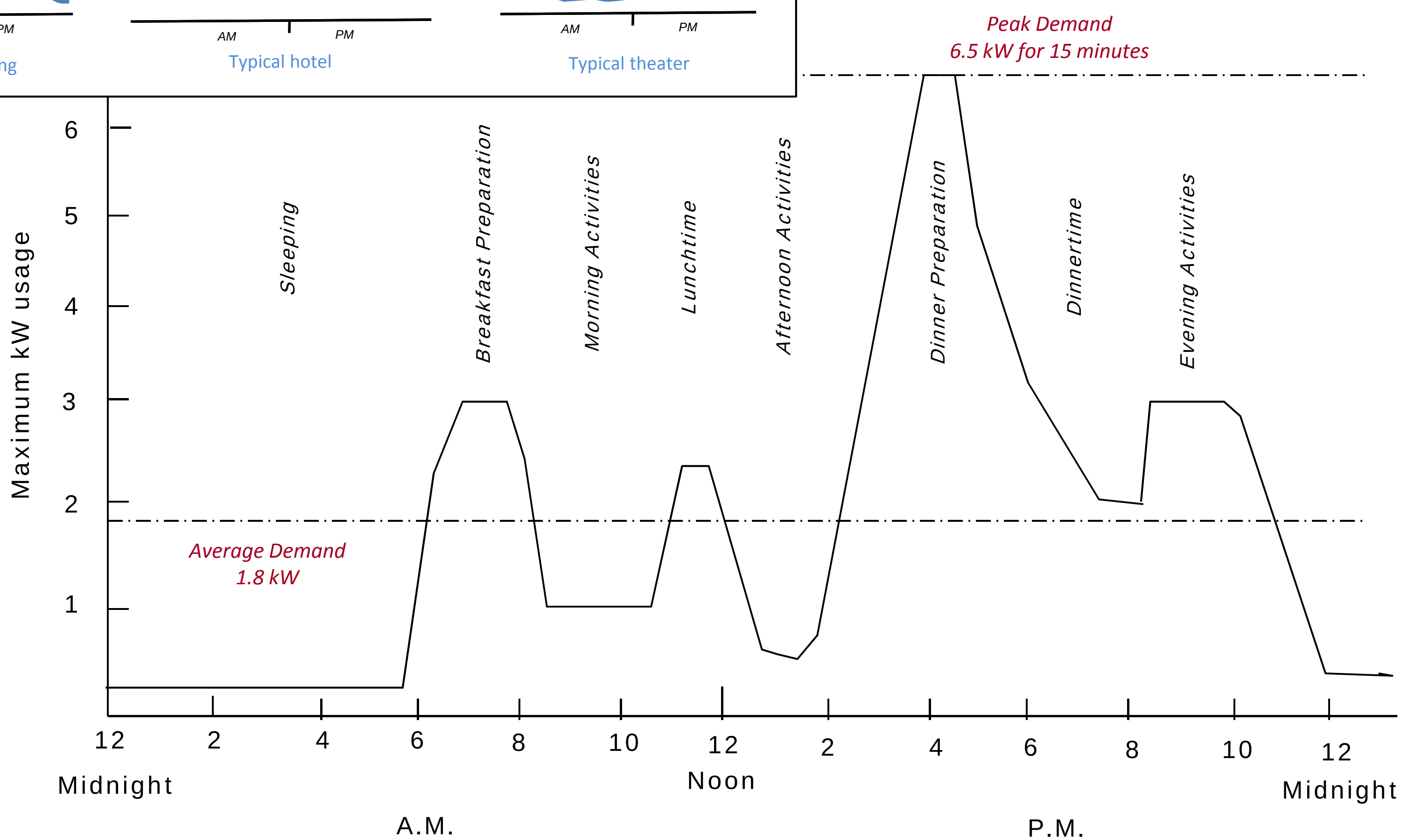
Key Section Objectives

- Illustrate how load and generation change over time
- Characterize who is involved in the operation of the electric system
- Describe how the electric system is operated today, and the complexity of the task
- Identify some of the emerging operational challenges

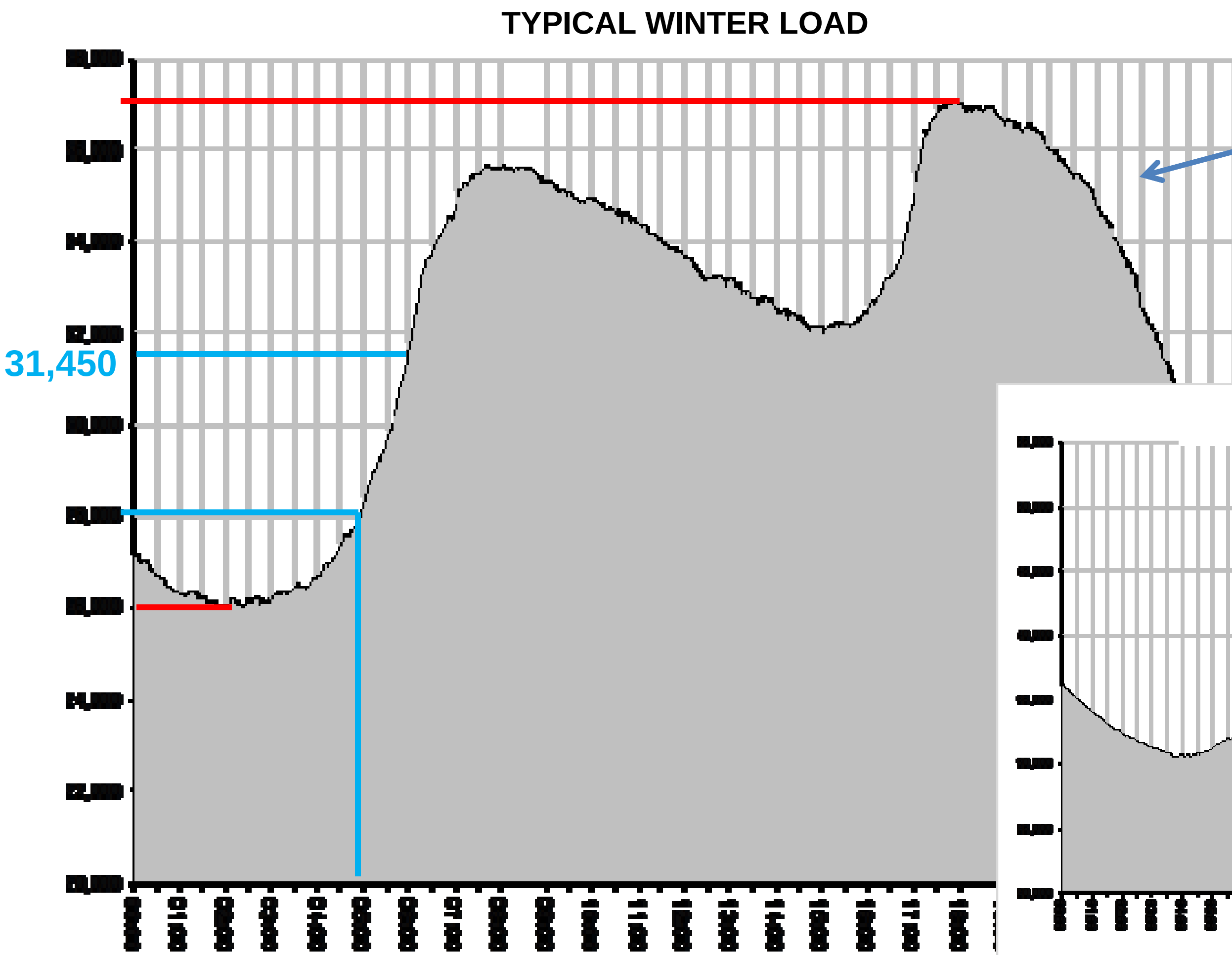
Load is not constant

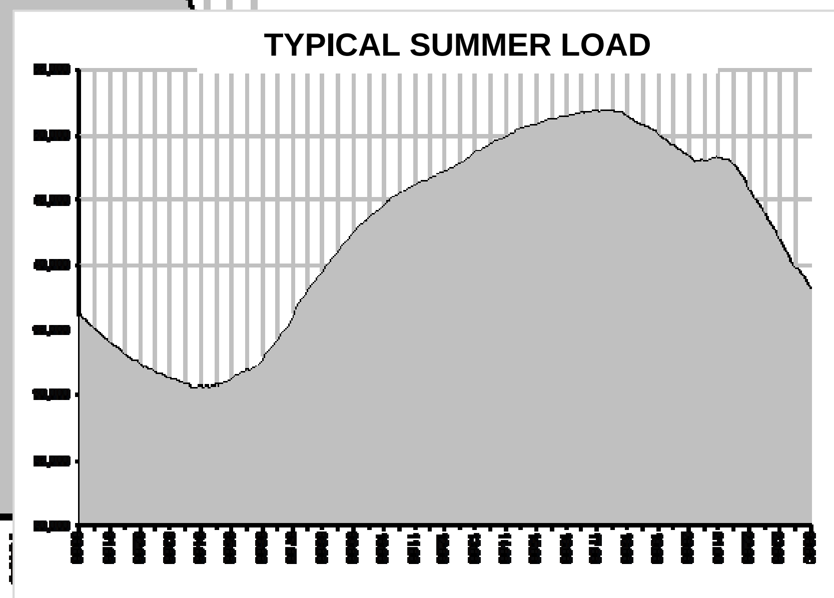


Hypothetical Power Usage for an American Household



Aggregate Load





PJM Winter Load

(Hypothetical Example)

Peak: 37,000 MW

Valley: 26,000 MW

LF Range: 11,000 MW

Max ramp rate between 5 and 6 AM:

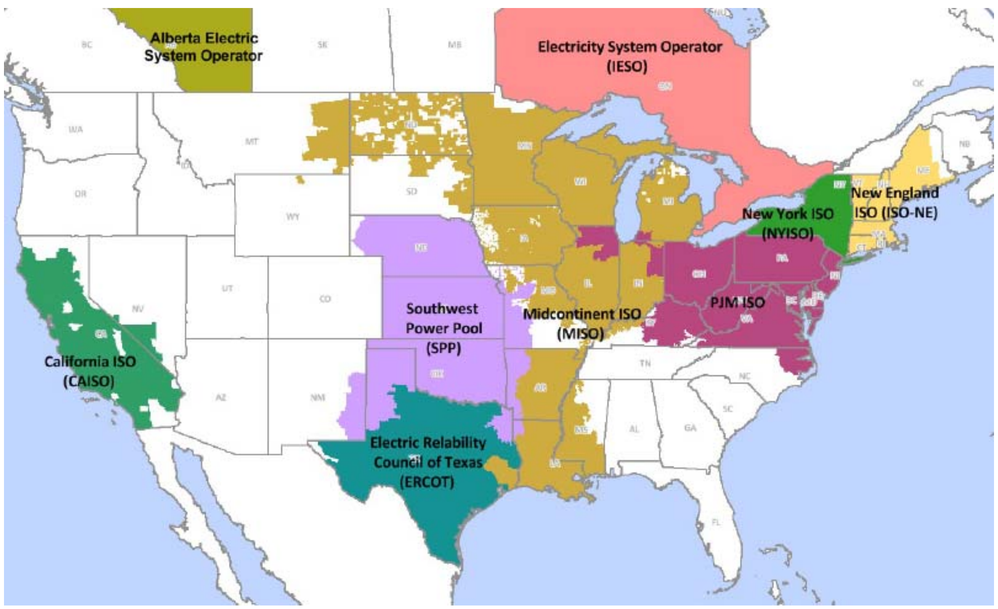
3450 MW/hr or

57.5 MW/min

Markets / Regulatory Structure

- U.S. has a blend of structured pool-based markets and traditional vertically integrated regulated areas
- State regulators are accountable for distribution and intrastate transmission rates
- FERC is responsible for interstate transmission

North American Regional Transmission Organizations



Source: ferc.gov

Regional Transmission Organizations (RTOs): *Independent entities, established by FERC Order 2000 issued in December 1999, that control and operate regional electric transmission grids free of any discriminatory practices.*

Bilateral vs. Organized Markets

- Bilateral contract – a buyer and seller negotiate directly and sign a two-party contract to trade electric power.

- Outside the RTOs/ISOs—mainly the Southeast and the West outside of California—wholesale power trades occur through bilateral contracts.

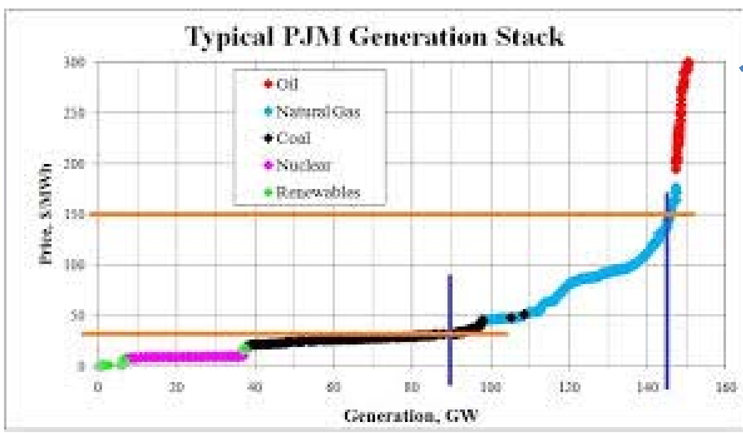
- Within the RTOs/ISOs, there are both bilateral trading and "organized" markets that pool all sellers and buyers.

Definitions:
RTO = Regional Transmission Organization
ISO = Independent System Operator

Economic Dispatch

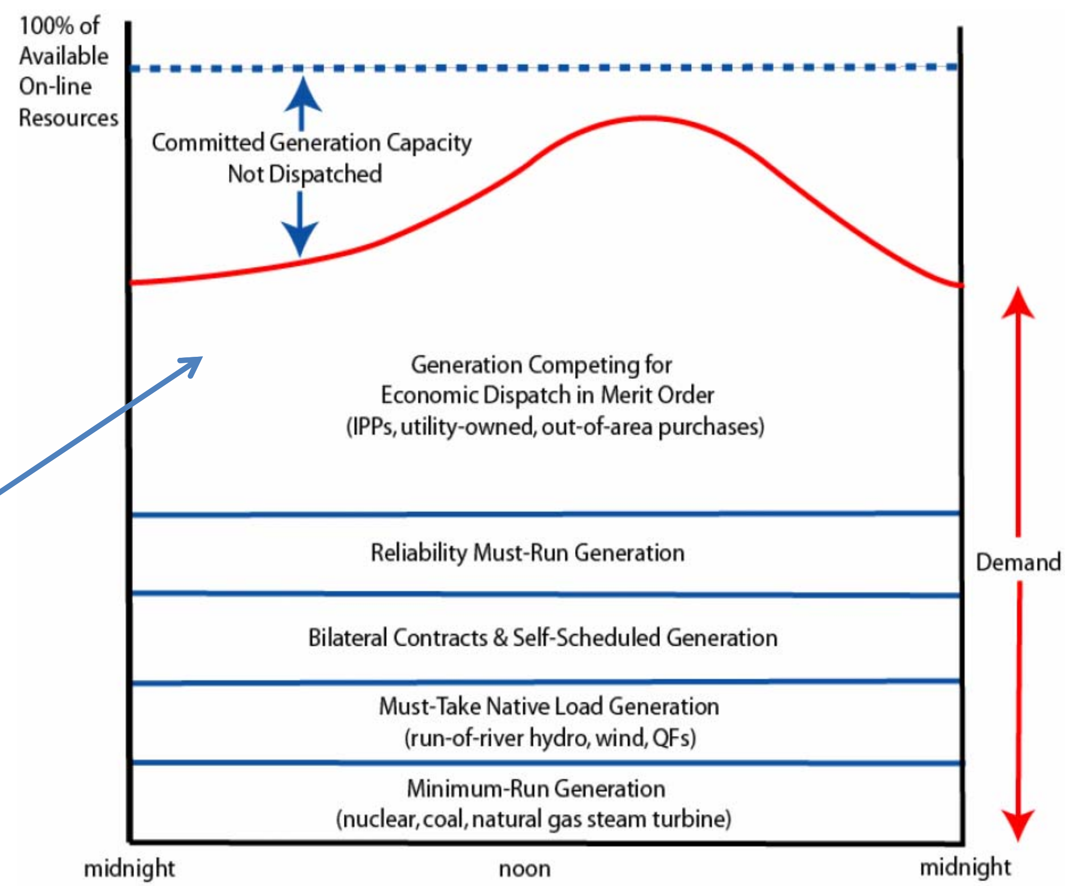
Economic Dispatch means "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities"

-- *Energy Policy Act 2005*, Sec. 1234 (b)



Source: e-education.psu.edu

Building the Economic Dispatch



Economic Dispatch Limits

Factors that affect and dictate grid constraints:

- Generation and transmission facility conditions and availability
  - Examples: whether a unit or line is out of service for maintenance or must operate under reduced limits
- Line capacities under different power flows and loading
  - *Thermal limitations* – transmission and distribution wires have limited capacity; heat can cause damage and excess sag.
  - *Angular Stability* – disturbances on the system (switching, contingencies, etc) may cause the system to become unstable and lose synchronism
  - *Voltage Stability* – high demand/loading on transmission can, with insufficient reactive power compensation, cause voltages to become unstable and difficult to control
- The availability and capabilities of other grid facilities to buffer and manage line loadings and voltages
  - Examples: circuit breakers, series or shunt reactive devices, transformers, and other equipment and protection schemes

System Operations

- Assuring system reliability per NERC standards at different system levels
  - Local
  - Balancing area
  - Interconnection
- Scheduling, dispatch, and control
- Transmission congestion management
- Measurements to monitor the system
  - State estimation
  - Contingency analysis
  - Load and generation forecasting
- Additional responsibilities
  - Ancillary services (and markets)
  - Security coordination
  - Emergency response and coordination

Source: TVA

Ancillary Services

Ancillary Services: services additional to provision of energy to support power system reliability

Normal Conditions

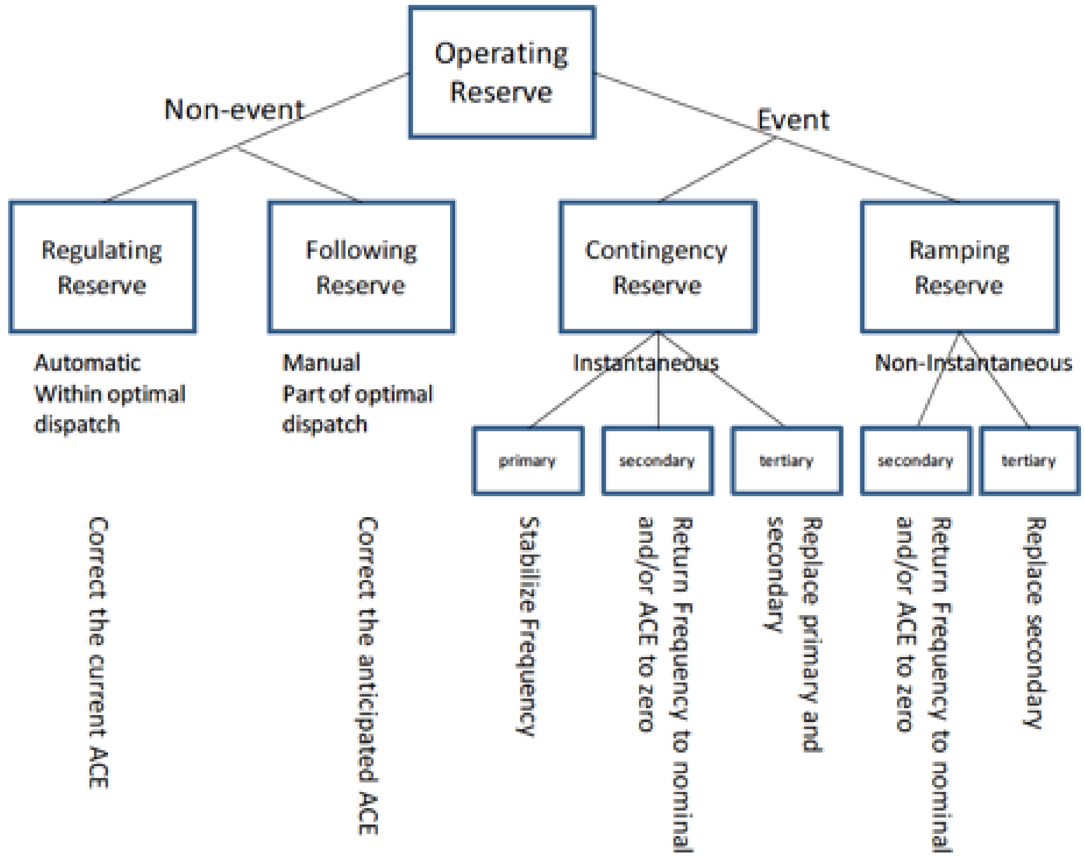
- Regulating reserves
- Load following reserves

Event Conditions

- Contingency
- Ramping

Other Services

- Voltage Control
- Black Start



Acknowledgement: PNNL

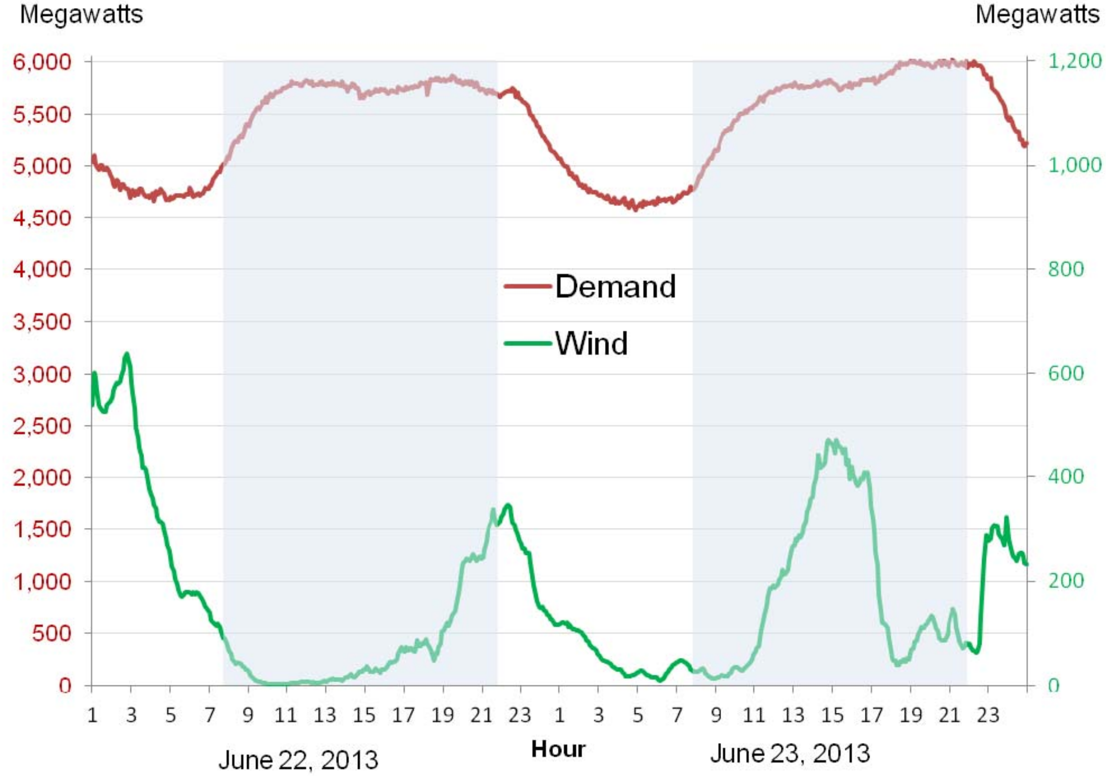
Operational Challenges

- The future generation resource mix is unknown
- The variability and uncertainty of renewable energy sources (e.g., wind and solar power) require new ways to operate the power system (including the use of storage, natural gas, demand response, inter-hour scheduling; market impacts)
- Load profiles are uncertain as on-site renewable energy resources, demand response technologies, and EVs/PEVs are introduced to distribution systems
- Valuation of ancillary services is evolving
- Boundary seams are critical for effective integration
- New concerns are continually emerging

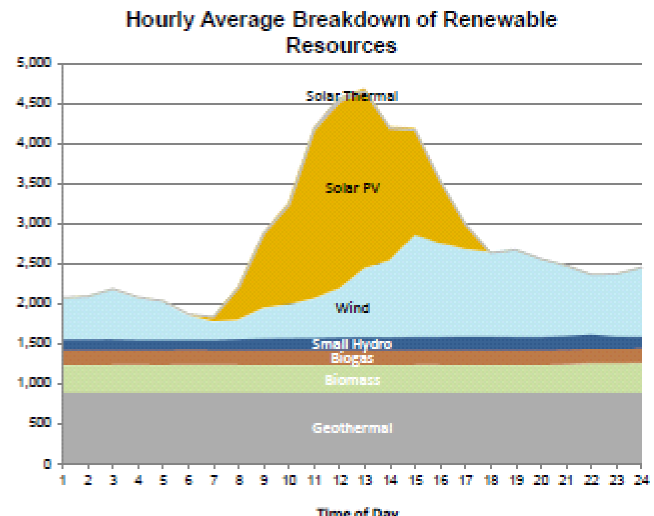
Definitions:
EV = electric vehicle
PEV = plug-in electric vehicle

Variable Energy Resources

Actual Demand and Wind Output for the Bonneville Power Administration, June 22-23, 2013



Actual Output of Renewable Generators in the California ISO, March 2, 2014



This graph shows the production of various types of renewable generation across the day.

Sources: EIA from Bonneville Power Administration data, California ISO [W. Booth, EIA]; Renewables Watch (CAISO)

Availability of Smart Grid Data Enhances Flexibility

Customer Systems	Advance Metering Infrastructure	Electric Distribution Systems	Electric Transmission Systems
			

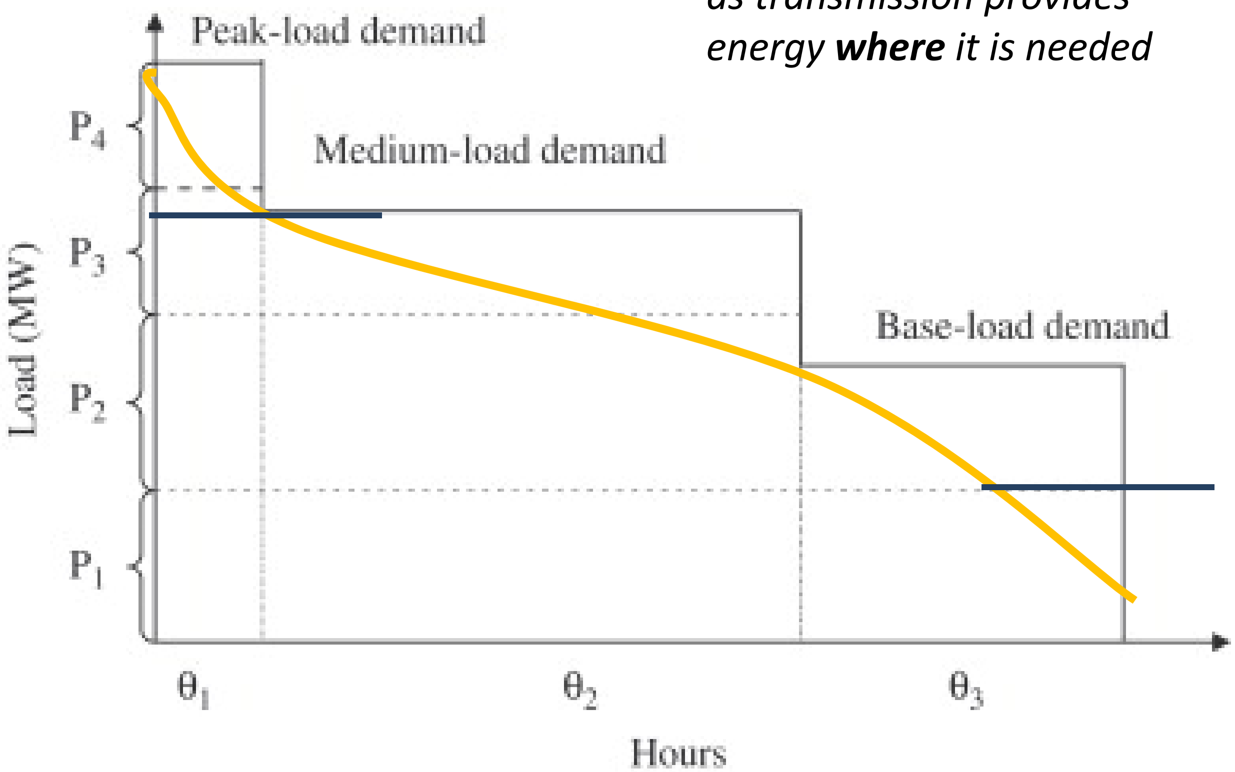
"Smart Grid" data sources enable real-time precision in operations and control to dynamically optimize grid operations to adapt to changing conditions

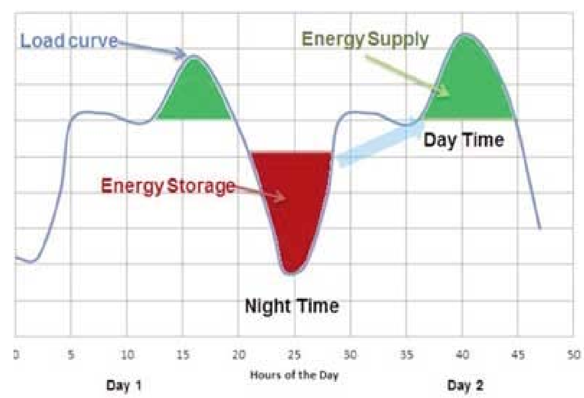
- Real-time data from distribution automation and smart meter systems will significantly advance real-time operations of distribution systems and enable customer engagement through demand response, efficiency etc.
- Time-synchronized phasor data, linked with advanced computation and visualization, enable advances in state estimation, real-time contingency analysis, and real-time monitoring of dynamic (oscillatory) behaviors in the system.

Energy storage would allow us to change the way we operate electricity systems

Energy storage provides energy ***when*** *it is needed just as transmission provides energy* ***where*** *it is needed*

- Responds instantaneously for peak shaving and bridge outages
- And makes renewables dispatchable





Source: DOE, Dr. Imre Gyuk; Sandia National Laboratories

Section Recap

- Operating Characteristics of Electricity
  - Demand varies considerably over the year, week and day.
  - Electricity storage is limited and expensive.
  - Electricity is produced the moment it is consumed.
  - Utilities rely on reserve capacity for unexpected loss of supply.
- Utilities dispatch resources to follow demand based primarily on lowest cost to consumers, while recognizing system limits.
  - Electricity market structures reflect regional diversity
  - There is a difference between cost and price of electricity.
  - Cost to generate electricity varies minute-to-minute.
- Opportunities for innovation and transformation exist to address emerging challenges

SECTION 3:
SYSTEM PLANNING

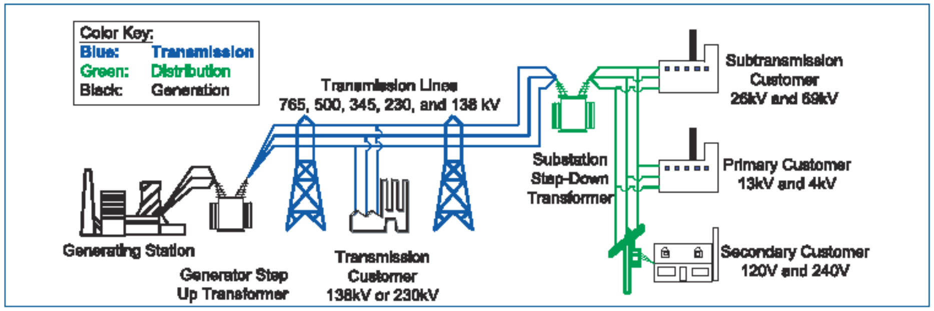
Key Section Objectives

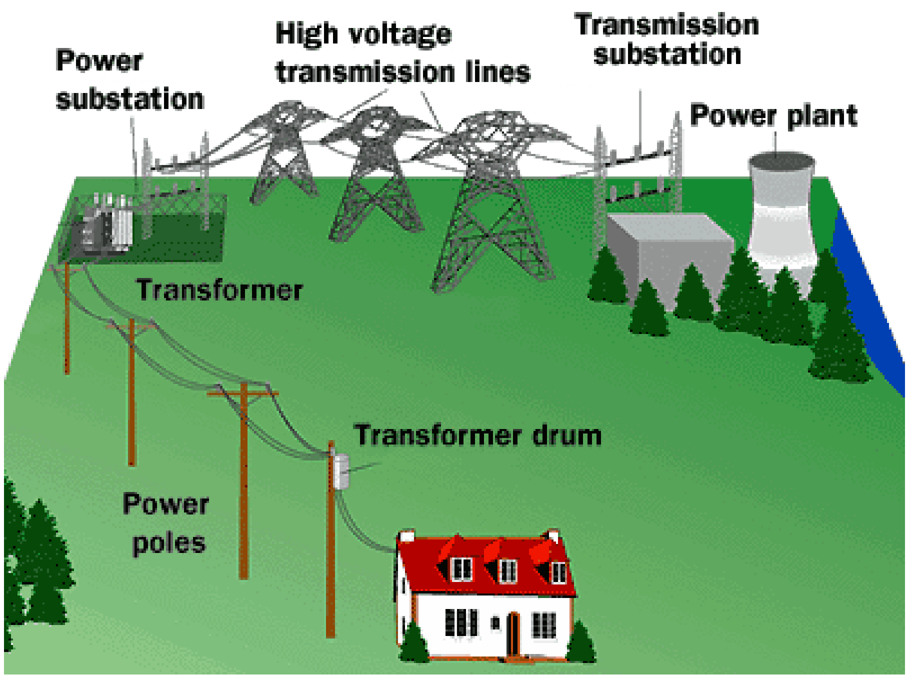
- Who develops system plans
- What is included in system plans
- When are system plans developed
- How are system plans are developed
- What are current system planning practices

Who Develops System Plans

- Within the Bulk Power System, the Planning Authority coordinates and integrates within its boundaries:
  - Transmission facility and service plans,
  - Resource plans, and
  - Protection system plans
- A Planning Authority Area is not constrained
- As of May 2015, there are approximately 74 entities which perform the Planning Authority function within the US

Key Elements of the Electric Power System Plans





Source: How Stuff Works

Three Major Components

Transmission facility and service plans

Whether elements are in or out of service and what the facilities future schedules are planned

Resource Plans

Future plans for generation and resources and their availability to deliver power to the grid

Protection System Plans

How protection system elements are configured on the system and what are their activation points

What is included in Future System Plans

- ✓ New Generation Resources
- ✓ New Transmission Infrastructure
  - Substations
  - Transmission Lines
- ✓ Upgraded Generation Units
- ✓ Upgraded Transmission Infrastructure
- ✓ Forecasts of generation retirements
- ✓ Technical System Requirements
  - Thermal requirements
  - Voltage Requirements

Southern Company – Kemper County | U.S. Department of Energy

The Vogtle Unit 3 cooling tower | U.S. Department of Energy, Photo courtesy of Georgia Power Company.

When are System Plans Developed

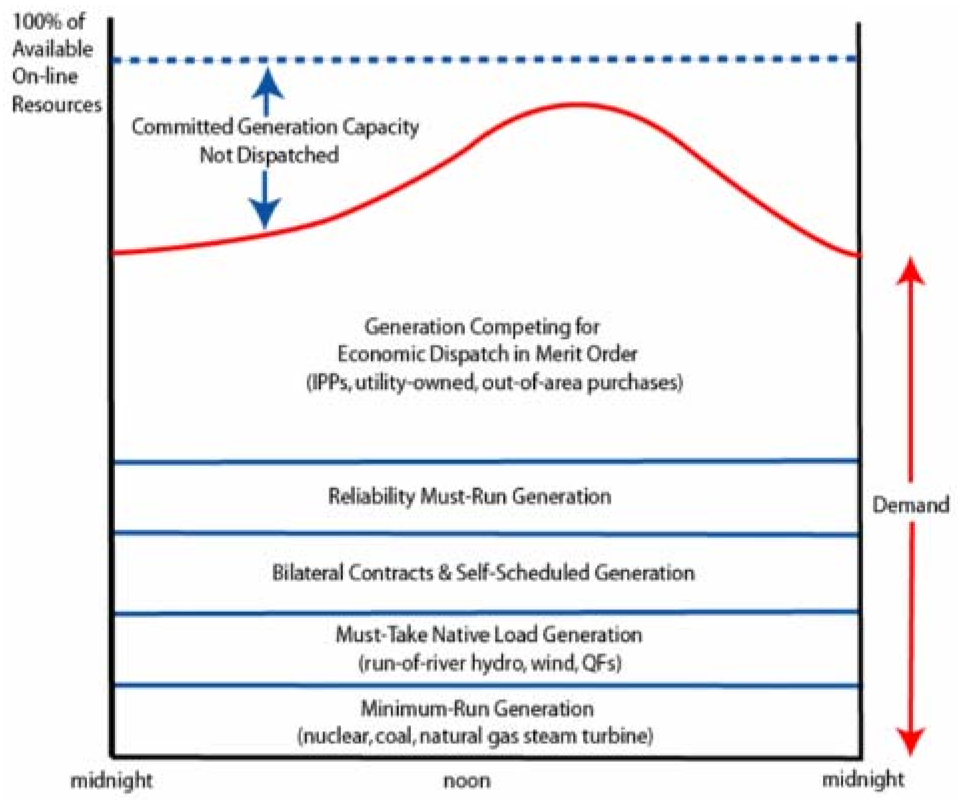
System Plans are developed on a defined cycle, typically occurring on an annual basis.

- The system plan development cycle is based upon a number of external factors and regional needs
- Check with your local Planning Authority to understand their cycle

How are System Plans Developed

What are Current System Planning Approaches

- Forecasting the availability of resources
  - Traditional resources
  - Renewables
  - Hybrid and New Tech
- Forecasting future loads
  - Economic Growth
  - Population growth
  - Other attributes
- Incorporating policy mandates
  - Loss of Load Expectation
  - Reserve Margin
  - Renewables and other mandates



Section Recap

- Who develops system plans
  - System plans on the bulk system are overseen by the NERC Registered Planning Coordinator
- What is included in system plans
  - System plans typically include forecasts of future electricity demand and future resource availability. Plans attempt to manage uncertainty
- When are system plans developed
  - System plans are typically formulated on a yearly basis by Planning Coordinators
- How are system plans are developed
  - System plans are typically developed through an open, technical process
- What are current system planning practices
  - Practices include resource forecasts, load forecast scenarios, and loss of load (contingencies) scenarios

SECTION 4:
RESOURCES FOR MORE INFORMATION

Federal Agencies involved in Electricity Systems Analysis

- U.S. Department of Energy
- Federal Energy Regulatory Commission
- Nuclear Regulatory Commission
- Energy Information Administration
- Environmental Protection Agency
- U.S. Department of Interior
- U.S. Department of Defense
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
- U.S. State Department

Helpful Data Resources

- **Form EIA-411** Coordinated Bulk Power Supply and Demand Program Report
- **Form EIA-860** Annual Electric Generator Report
- **Form EIA-861** Annual Electric Power Industry Report
- **Form FERC-714** Annual Electric Balancing Authority Area and Planning Area Report
- **Form OE-417** Electric Emergency Incident and Disturbance Report

Additional Federal Resources

U.S. Department of Energy
- Quadrennial Energy Review
- National Electric Transmission Congestion Study

Federal Energy Regulatory Commission
- Energy Infrastructure Update (*Monthly*)
- Market and Reliability Assessment (*Semi-Annual)*

Energy Information Administration
- Short-Term Energy Outlook
- Annual Energy Outlook
- Electric Power Monthly

Thank you

Presenters:

Gil Bindewald
Office of Electricity Delivery and Energy Reliability
U.S. Department of Energy
gilbert.bindewald@hq.doe.gov

Eric Rollison
Office of Electricity Delivery and Energy Reliability
U.S. Department of Energy
eric.rollison@hq.doe.gov

Electricity Policy Technical Assistance Program:

Caitlin Callaghan
Office of Electricity Delivery and Energy Reliability
U.S. Department of Energy
caitlin.callaghan@hq.doe.gov